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The Nature of Forgeries: Iron Gall Ink and Paper Aging in Relation to Forged Historical Documents- An Independent Study

Abstract

This paper aims to, first, highlight some previous methods of aging iron gall ink and paper for the purpose of forging historical documents. Second, this study is one of materials, exploring the components of iron gall ink in different recipes, and how these components react to artificial aging through heat, humidity, sunlight, and chemical treatments. Paper and ink samples were aged using these methods, then analyzed with a microscope, ultraviolet light, and ambient light. The ink sample which displayed the fewest signs of being aged artificially was applied to non-collections material in an attempt to create a "fake" forgery. This study is not one on forging the content of a document. It is meant to illuminate the mechanisms and science behind the aging of ink and paper in relation to forged historical documents, and not intended to be a serious attempt at the craft of forgery.

I. Background

A. The Components of Iron Gall Ink

Iron gall ink is made from four primary ingredients: tannin, iron sulfate (vitriol), water or wine, and a binder, most commonly gum arabic. The ink is created when tannic acid and iron (II) sulfate react together in an aqueous solution to produce a chromophore. The active components in tannin are tannic acid and gallic acid, and these acids react with the iron (II) sulfate to produce a black pigment called ferrogallotannate or ferrotannate upon exposure to oxygen (Karnes 2005). This complex is not water soluble, contributing to the indelibility of iron gall ink.

i. Tannic Acid

Tannic acid is found in the galls, bark, roots, fruits, and leaves of various plants. The greatest concentration of gallotannic acid is found in galls, growths formed on the leaves and twigs of trees in response to parasitic attack. Galls are collected from oak-apple, oak, and pistachio trees, and differ in shape and concentration of tannins depending on the source. There are three different methods by which gallotannate was historically extracted from galls. Some ink recipes call for the galls to be crushed or powdered before addition to water or other liquid. Others call for the galls to be boiled for a length of time so tannins are released. More time consuming is the third method, which involves the fermentation of galls by mold. This process usually produces the richest and blackest inks. The mold digests the gallotannic acid, converting it to gallic acid. Gallic acid will produce a very black color in reaction with iron (II) sulfate, while gallotannic

acid will produce a browner pigment (Karnes 2005).

ii. Iron (II) Sulfate
Also called, vitriol, ferrous sulfate, and copperas, the pure form of iron (II) sulfate can be obtained through chemical or art suppliers, and is pale green in color. A less pure form can be made from dissolving iron scraps or nails in a weak acid, and this is more often the case historically (Karnes 2005).

iii. Water or Wine
Most iron gall inks are made in water. Generally, fresh water, or distilled water is better because tap water may be contaminated with chlorine, salts, and metals from pipes. Historically, rainwater was considered the best source for pure water. Wine, beer, or other vinegars have been used to make ink because they were thought to be purer liquids than tap water or standing water. Alcohol may increase the rate of extraction for tannin, and may also have a preservative effect by inhibiting mold from growing on the surface of the ink. It also reduces the surface tension of the ink, allowing it to soak more quickly into the fibers of a paper (Karnes 2005).

iv. Binder
The binder keeps the black pigment of iron gall ink suspended in the liquid. It also helps thicken the ink, allowing for better flow through the writing instrument to the paper. The binder holds the ink at the surface of the paper for a few seconds before the ink sinks into the fibers, influencing the appearance of the ink by making it clearer and sharper than it would be without a binder. Typically the binder in iron gall ink is gum arabic, a water-soluble resin collected from the Acacia tree (Karnes 2005). Gum arabic helps prevent precipitation of the ink when the ferric gallate pigment of iron gall ink, made from gallic acid and iron sulfate, is exposed to oxygen.

Rarely, other binding agents such as egg white are mentioned as having been used historically in iron gall ink manufacture (Eusman 2005).

v. Other Ingredients
After the tannic acid for ink was obtained and mixed with vitriol and the binder, other ingredients were sometimes added to modify characteristics of the ink. Natural dyes such as logwood could be added to increase the visibility of freshly prepared ink. Pomegranate rind, walnut husks, various tree barks (Eusman 2005), horse chestnuts, and hemlock might be added for extra tannin, but the tannins in these materials tend to be less durable and exhibit a green tone rather than the blue black tone characteristic of quality iron gall ink (Karnes 2005). Vinegar or other acids may be added to mitigate premature precipitation of the ink. Sugar, honey, or gum will create a more brilliant and slow-drying ink. Carbolic acid, cloves, alum, salts, vinegar, or alcohol may be added to slow mold growth, and alcohol, specifically brandy, might protect against freezing (Eusman 2005).

B. Famous Forgers and Forgeries

Many documents now confirmed to be forgeries were once easily passed off as valuable documents. Often, any obvious signs of fakery in materials or content were overlooked simply because the viewer wished the object to be genuine. And in many cases, the forgery was so

skillfully executed that it was only revealed as a forgery upon very close examination, after the document had changed hands many times. The skill of famous forgers has ranged from crude to genius. Their motives for forgery may have been money, fame, revenge, curiosity, or in the case of some, they were simply criminals from childhood. In order to understand the materials used when creating a forgery, I needed to understand the methods of creating forgeries, and the mistakes made by the minds behind them.

i. Antique Smith

Alexander Howland "Antique" Smith of Edinburgh was sent to prison for a year in 1893 for forging a considerable number of letters purported to be written by respected literary authors such as Robert Burns, Sir Walter Scott, Thackery, and other celebrities. These forgeries were created using blank leaves of paper from the appropriate periods. Some of Smith's forged letters showed wormholes consistent with their age, but suspicion was aroused when it was noticed that in every instance the worms had avoided the writing (Mitchell 1935, 25). Other documents purported to be from the seventeenth century had been written in modern ink, with a steel nibbed pen, and the letters had been yellowed with the help of a weak tea bath (Fergus 2005).

ii. Joseph Cosey

Joseph Cosey was born in 1887. His real name was Martin Coneely, and he was a clever student partial to American history. Cosey began forging checks as a teenager and was a petty thief after being discharged from the army. Soon after this time his criminal activities landed him in jail for almost 10 years. He was released in the late 1920's and began his serious career as a forger in 1929. His forgery career began when he stole a Benjamin Franklin pay warrant on a visit to the Library of Congress. After showing the pay warrant to a dealer who claimed it was a fake, Cosey decided to get revenge by buying a bottle of brown ink, practicing the handwriting of famous Americans, and forging several documents which he then sold.

Cosey soon became a master at fabricating handwriting and created forgeries of Benjamin Franklin, Mary Baker Eddy, George Washington, Aaron Burr, Patrick Henry, John Adams, James Madison, and many others. He used period paper, and wrote with ink that looked strikingly similar to ink of the appropriate time. His faults were mainly two: First, his ink would not have passed physical tests, as it was simply brown colored fountain pen ink. Second, he did not use a quill pen, but instead a steel nibbed pen, which was not in common use until the 1840's (Hamilton 1996).

iii. Mark Hofmann

Mark Hofmann was the first forger known to have an extensive knowledge of chemistry. He is the most skilled known forger of our time, going to great lengths to make his forgeries. He was born in 1954, and his career in forgeries was flourishing by the early 1980's. Hofmann found period papers by stealing blank pages from nineteenth century books in a library, and he made iron gall ink from an authentic formula found in a book. To avoid ink feathering when using the new ink on old paper, he dipped the paper in a gelatin solution to resize it. After writing on the paper with a quill pen, Hofmann would treat the paper with a chemical solution, either by dipping the document in the solution or spraying the solution on the document. For this process of aging, Hofmann used hydrogen peroxide, sodium hydroxide, ammonium hydroxide, or some combination of these chemicals. Some of Hofmann's documents were dried by hanging, while

other documents were dried using a homemade suction table, which was meant to draw ink through to the back of the paper, mimicking age (Hamilton 1996).

When his forgeries were later examined under ultraviolet light, the ink appeared to be running in one direction, rather than haloing out evenly, a phenomenon due to hanging the paper to dry (Roberts 1988). Microscopic investigation of Hofmann's forgeries showed a cracking of the ink. This cracking came to be known as alligator ink, and was thought to be caused due to the gum arabic in the recipe undergoing a drastic viscosity change upon exposure to the chemicals used for artificial aging. Treating paper with these chemicals also caused a blue hazing effect seen under ultraviolet light (Tanner 1987).

C. The Goal of This Study

Based upon these stories of forgery, especially Mark Hofmann's methods, I sought to find a way to age iron gall ink without ink cracking. Because I was aging the paper in addition to the ink, I also sought to do this without creating the blue hazing effect seen under ultraviolet light. By more thoroughly understanding the methods and materials of forgers, I felt that I might discover better methods of examining questioned documents. Again, I did not attempt to match the content and the handwriting of these forgeries to a specific period, as I was only concerned with aging and examination of the materials.

II. Initial Investigation

A. Sample Preparation

Eight iron gall ink recipes, listed in Appendix A, were chosen for this experiment. Some were historical recipes, and a few were modified in an attempt to avoid ink cracking by replacing gum arabic with another possible binder or humectant such as egg white, sugar, or honey.

The paper chosen for samples was a medium weight, handmade, wove paper from 1865. It was off white in color, of good quality, and flexible. Fiber analysis using a polarizing microscope showed the paper to be made of cotton fibers. The paper was found as endsheets in a discarded book published in 1865, and was used for this project because of its appropriate age and available quantity. The paper was cut into 32 squares of approximately 2" x 2", and each square was labeled in pencil with a recipe number and method of chemical aging. Four samples were prepared for every recipe: a control, and three samples which were to be aged chemically. Each ink was applied to four paper samples over a large area using a Japanese brush, so that effects of aging might be easily identifiable. The samples were allowed to dry and condition to the air for two days. Note: The inks at this stage were not yet 100% filtered due to time constraints, as I wished to observe which recipes may be possibilities for use in the final application before investing filtering time in all eight of them.

B. Experimental Stage

Before aging chemically, all samples, including controls, were aged with sunlight, heat and humidity. The samples were tacked to a board and placed in direct sunlight for 2 weeks in Texas in August. Average temperature for this time period was 99º F, and average relative humidity was 85%. Exposure to these conditions seems to have slightly darkened the paper, lightened the ink, and embrittled each sample.

Chemical aging processes began the day after removing samples from the sunlight and humidity. One sample of each ink recipe was left out of this aging process as a control, the three other samples were each aged with a different chemical, each chemical in a separate fume chamber created by placing a beaker of the chemical in the center of a plastic box, the paper samples around the inside perimeter, and sealing the box. Inspiration for this chemical aging experiment came directly from my investigation into previous forgery attempts. For each ink recipe, one sample was aged with the fumes of 28-30% ammonium hydroxide, one with the fumes of 0.1 M sodium hydroxide, and one with the fumes of 3% hydrogen peroxide. Volume levels in beakers were checked every other day to ensure that the chemicals were not volatilizing too quickly.

C. Discussion of Results

The samples were aged for 10 days and then visually examined through the clear boxes. The hydrogen peroxide samples showed the least degree of color change. Driven by curiosity, I removed the samples from the chamber and washed them each for 30 seconds in 3% hydrogen peroxide to observe the results. In some instances there was immediate bleaching of the ink, and in some cases more time passed before a dramatic change in the ink occurred. In all cases, after drying between blotters and boards, the peroxide visibly lightened the paper and the inks were bleached to varying degrees, some more consistently than others (Table 1).

Table 1. Visual effects of hydrogen peroxide bleaching on ink

Recipe	**Visual effects of bleaching with H2O2**
ink # 1	light brownish black color
ink # 2	inconsistent bleaching, black particles throughout, ink is darkest around edges, the edges have haloed, color ranges from brownish black to light brown
ink # 3	remains nearly black, edges are haloed and brown
ink # 4	similar to # 2 but more bleached with smaller particles of black
ink # 5	haloing around edges has been carried further than any other sample and is light brown in color, ink appears dry and powdery, color is dark gray, bleaching has highlighted the chain and laid lines in the paper
ink # 6	previous spots of unfiltered gallic material have fallen or flaked off to leave behind light gray spots, otherwise the ink remains nearly black
ink # 7	color has faded to a light warm brown, haloing is seen at edges, some particles of black remain where there has been inconsistent bleaching
ink # 8	has faded to a light beige color not much darker than the paper, and is slightly darker around the edges

Sodium hydroxide samples showed a very slight change in paper and ink color after 10 days, and were left in the fume chamber for one month total. These particular samples did not exhibit a drastic change in ink color. In fact, they remained almost unchanged in ink appearance except for a slight haloing of the ink around all edges of the ink area. The paper showed a mild degree of darkening, or aging.

Ammonium hydroxide samples showed the most notable color change in ink after 10 days, and were also left in the chamber for one month total. After one month, the ink appeared to be a dark rusty brown color with even haloing around all edges, as if the ink had been applied to the paper some time ago. The paper had also considerably aged, turning darker and more yellow or brown. It appeared to be more brittle than other samples, and was when touched or bent at a corner. These results would be very desirable for a forgery.

All samples were examined under ultraviolet light, and the florescence of each paper and ink sample was compared to its control. The control samples fluoresced as expected, showing the ink to be a velvety black color and the paper to be grayish orange in tone. Ammonium hydroxide and sodium hydroxide samples fluoresced similarly, and showed no signs of unusual blue tone or uneven haloing from chemical aging. Hydrogen peroxide samples fluoresced differently because both the paper and ink had been chemically bleached, so the ink in this case fluoresced a purple brown rather than a dark velvety black. The paper showed streaks of different tones and inconsistencies in ink density, caused by running of the ink during washing in hydrogen peroxide.

All samples were examined microscopically for signs of ink cracking. Inks of chemically aged samples appeared to be in interaction with the paper fibers as exhibited in the controls. Shrinking and cracking of the ink was not observed in the recipes in which gum arabic had been included, even in the densest areas of ink application.

D. Conclusions

Of the eight ink recipes made, Recipe # 1, aged with ammonium hydroxide, was chosen as the method to continue with for several reasons. This ink produced the most desirable aging effects when viewed under ambient light, appearing darker, more brittle, and older in both ink and paper characteristics. When compared to all other samples, the ink of this sample appears the most consistently rusty and dark brown in color, visually mimicking authentic nineteenth century iron gall ink. Under ultraviolet light, this sample exhibits the same fluorescence as would an authentic document written in iron gall ink on period paper, and shows no evidence of chemical aging through a blue tone or unusual haloing or feathering. The sample does not give off the smell of being exposed to a chemical, and shows no microscopic evidence of ink cracking. Also, this particular recipe is a historical one that was not altered at all in production: if the ink were tested, it should appear authentic in its makeup.

III. The "Fake" Forgery

A. Materials and Aging

The non-collection materials chosen for this stage were early twentieth century postcards, cartes de visites, and one booklet. A variety of materials were chosen in order to observe how different paper supports might react to the addition of new ink and artificial aging. Fiber analysis was done on each support (Table 2).

Table 2: Fiber analysis results for "fake" forgery items

Item	**Fiber analysis results**
Cornhill Booklet, July 1901	cotton linters
Photocard of woman	flax, nonconiferous chemical wood
Photocard of family	straw, nonconiferous mechanical wood
Postcard of house	nonconiferous mechanical wood
Postcard of England	nonconiferous chemical wood
Postcard of architecture	nonconiferous chemical wood

The items were not resized. The ink of Recipe # 1 was applied to all samples using a steel nibbed pen, which caused the ink to occasionally splatter when hitting a sharp point in the paper. This is a normal characteristic of writing with a steel nibbed pen or a quill pen, and an important one to recreate in the case of a forgery. I did not attempt to match handwriting or language characteristics to those of the early twentieth century, as the content of these items was not a part of my materials study of forgeries.

All items were aged following the same method performed in the initial experimentation of this study, fumed for one month in a chamber containing a beaker of 28-30% ammonium hydroxide.

B. Results

When the box was opened and the items were examined visually, it was noticed that the color change in the ink was not as drastic as the change in the experimental samples. This is likely because the concentration of ink is much less over the area of the item, since the ink was applied with a pen in thin strokes rather than with a brush with heavy strokes. Color change of the iron gall ink varied from one item to the next. Some samples showed effects of ink darkening only, and others showed darkening as well as a color change to dark rust brown. The papers appeared slightly yellowed or browned, as if mildly aged.

For all aged items, the paper and ink fluoresce as they should for iron gall ink on period paper, showing similar characteristics to those observed under UV with the initial paper and ink samples aged with ammonium hydroxide. There is no blue tone caused by chemical aging, and no uneven haloing of the ink. The items were also examined microscopically to check for evidence of ink cracking due to artificial aging. Again, no cracking was observed, even in the densest area of a stroke.

Proceeding as a document examiner would when verifying the authenticity of an item, two chemical tests for iron were performed. The first was a test for the presence of iron (II) ions using an indicator paper containing bathophenanthroline (PEL 2003), which forms a magenta colored complex with iron (II) ions. The indicator paper was dampened with distilled water and pressed to the ink for 30 seconds. The test was slightly positive for the presence of iron (II) ions. The second chemical test performed was one for the presence of iron (III) ions (Tabasso 1993), in which hydrochloric acid and potassium ferrocyanide were respectively applied to extracted fibers from areas saturated with ink. The fibers were first bleached by the acid, and then turned blue from the potassium ferrocyanide, indicating a positive test for the presence of iron (iii) ions. When extracting fibers of ink from the items, the fibers in areas saturated with ink appeared to be weaker than those not saturated with ink, another indication that the ink is iron gall and has begun to degrade the paper fibers.

C. Conclusions

My analysis of the forgeries I created allowed me to come to several conclusions from a document examiner's perspective, and I found two problems that might dispute the authenticity of these materials were they actually forgeries. The first is an offsetting of the ink when the damp indicator paper was pressed to it for 30 seconds. The more the ink is exposed to oxygen, the less soluble it will become. When iron gall ink is manufactured, it penetrates the paper well because of its solubility. This is the reason iron gall ink is so difficult to erase, and at this stage the ink is in the form of ferrous gallate. When exposed to oxygen, the ink oxidizes to become ferric gallate, which is not water-soluble. Since I did not add a provisional colorant to this recipe, I knew that this was not dye offset, but ink offset. This means that the ink itself is still immediately water soluble, and may possibly indicate to a document examiner that the ink is fairly new.

The second problem I observed involves the paper fibers underneath the ink stroke. In this case, the fibers under the ink stroke remain their original color, again indicating to an examiner that this ink may be fairly new. If when written, the ink did not come into contact with some of the paper fibers, the haloing of the ink over time should have turned these fibers underneath the ink stroke a darker color. So, if the item were old enough, the paper fibers underneath the ink stroke should have turned brown.

There may be several reasons I did not experience the same ink cracking or blue hazing effect from aging as forgers have experienced. First, I did not size any of my samples with gelatin before applying ink to them. In famous forgeries, the gelatin on the paper may have actually contributed to those negative effects of chemical aging. I also aged my samples with only one chemical in a controlled way, and the ink cracking or blue hazing effects seen in previous forgeries may have come from aging the document with a combination of chemicals. And, I aged only with chemical fumes and did not spray or bathe my samples with chemicals as other forgers have done.

If I were to go further with this materials study, and attempt to address the problems I have just outlined, I would proceed with two primary experiments. First, I would add a provisional colorant to the ink recipe, which may slightly dye the paper fibers underneath the ink stroke,

perhaps causing those fibers to appear stained from age. A provisional colorant may also create a reason for immediate offsetting of the ink when put into contact with dampened paper. I would also attempt to dry the paper on a suction table in an effort to bring the ink further into the paper fibers, possibly causing coloration under the ink stroke. Second, I would size my samples with gelatin before applying ink to them. This would prevent feathering of the ink, and also allow me to determine whether or not ink cracking might be caused in part due to gelatin sizing and not gum arabic.

From the point of view of an examiner, not a forger, my general conclusion is that if a document examiner is thorough, I do not yet see a way to leave a forgery entirely undetected. It may easily be left in question, meaning that it cannot positively be deemed a forgery based on materials examination alone. I feel it would be relatively simple to develop the craft of forgery to such a skill that a document could be passed off as genuine. Again, I am referring to materials only, and not the tasks of forging handwriting, printing, or content. Based on this study of materials, I believe it is possible to create a document that looks genuine to the naked eye, and even to a degree under microscopic and ultraviolet examination. The results of this study now give me a sharper eye to look for possible flaws when examining questioned documents.

Appendix A: Ink Recipes

Recipe #1:
2. 5 grams gallnuts
0.5 grams ferrous sulfate
0.5 grams gum arabic
100 ml water

Gallnuts were ground to a fine powder using a mortar and pestle, then a coffee grinder. The powdered gallnuts were immersed in half the water (50 ml), contained in a jar, and placed in the sun for 2 days. The liquid was left to sit for 5 more days, and then filtered. The gum arabic was added to 25 ml of water and dissolved, then this liquid was added to the filtered gallnut liquid. The ferrous sulfate was dissolved in 25 ml of water, and added to the mixture.
"Iron-gall ink (1)", Lindquist. Amounts of ingredients were cut in half for this experiment.

Recipe #2:
3 grams gallnuts
2 grams ferrous sulfate
1 gram gum arabic
30 ml water

Galls were finely crushed and added to water. The mixture was stirred and left to stand in a closed jar in the sun for two days. The ferrous sulfate was added, stirred, and the mixture was left to sit for two days indoors. Gum arabic was then added and the mixture was stirred, filtered, and returned to the jar.
"Basic Ink Formula", Lindblad.

Recipe #3:
0.9 grams pure tannin (tannic acid)
1 gram ferrous sulfate
0.5 grams gum arabic
15 ml red wine

The wine was heated to 50 degrees Celsius, at which point the tannic acid was stirred into the wine. Ferrous sulfate was then added, with continued stirring. Gum arabic was added last, and the mixture was stirred until the gum arabic was dissolved. The ink was cooled and poured into a jar, unfiltered.
"An Ink for Hectic Types", Lindblad.

Recipe #4:
2.5 grams gallnuts
1 gram ferrous sulfate
0.5 grams sugar
100 ml water

Crushed galls were added to half the water and boiled for 30 minutes. As water was lost to steam, small amounts of water totaling 50 ml were added to replace the liquid. The gall water was cooled and filtered. For experimentation, 0.5 grams gallic acid was added to the mixture before filtering, causing immediate darkening of the liquid. Ferrous sulfate and sugar were dissolved in 15 ml of water, and added to the gall water.
My own recipe.

Recipe # 5:
5 grams gallnuts
4 grams ferrous sulfate
2 grams honey
200 ml water

Crushed gallnuts were boiled in 100 ml of water for 1 hour, adding an additional 100 ml of water as needed. Honey was added to the boiling water, then ferrous sulfate. The mixture was immediately cooled and filtered.
My own recipe.

Recipe #6:
4.375 grams gallnuts
2.625 grams ferrous sulfate
1 egg white
30 ml of red wine (changed from 15 to thin the mixture)

The egg white was mixed into the red wine, then crushed gallnuts and ferrous sulfate were added, respectively. The mixture would not filter due to the presence of egg white.
"Instant ink", Karnes. Modified by replacing gum arabic with an egg white. Amounts of all other ingredients were divided by 8 from the original recipe.

Recipe #7:
1.7 grams gallic acid
0.3 grams tannic acid
2 grams ferrous sulfate
1 gram honey
30 ml red wine

The red wine was heated to 50 degrees Celsius. Tannic and gallic acids were dissolved in the red wine, and then ferrous sulfate and honey were added, respectively. The mixture was cooled and jarred unfiltered.
My own recipe.

Recipe #8:
As the mixture from Recipe #7 was quite thick, much of it still remained on the sides of the container after the ink was poured into a jar. To this original container, 100 ml of water was added, creating much thinner ink. This ink was designated as Recipe #8, although it is simply a thinner version of Recipe #7 and not a new recipe.

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